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Weight and volume changing device with liquid metal transfer

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Weight and Volume Changing Device
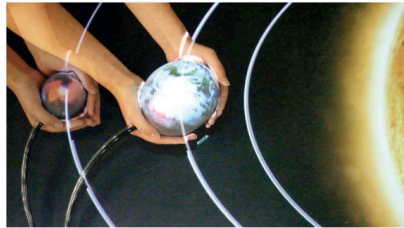# with Liquid Metal Transfer

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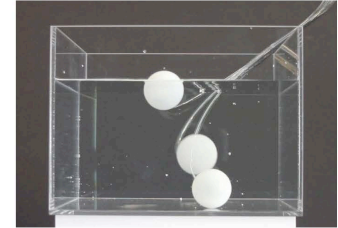liningy@media.mit.edu

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(a) weight-changing (b) weight-changing + volume changing (c) motion control by gravity force

Figure 1. Basic concept of the weight-changing device: (a) weight-changing (raw material simulation with textures of pine wood and aluminum alloy projected on the device), (b) simultaneous weight/volume-changing (miniature planets with scaled mass/size), (c) motion control using gravity force (buoyancy control in a water tank)

ABSTRACT
This paper presents a weight-changing device based on the transfer of mass. We chose liquid metal (Ga-In-Tin eutectic) and a bi-directional pump to control the mass that is injected into or removed from a target object. The liquid metal has a density of $6.44 g/cm^3$, which is about six times heavier than water, and is thus suitable for effective mass transfer. We also combine the device with a dynamic volume-changing function to achieve programmable mass and volume at the same time. We explore three potential applications enabled by weight-changing devices: density simulation of different materials, miniature representation of planets with scaled size and mass, and motion control by changing gravity force. This technique opens up a new design space in human-computer interactions.

Author Keywords
Weight-Changing, Shape-Changing, Tangible Interface, Liquid Metal, Human-Material Interaction, Haptic Display, Gravity

ACM Classification Keywords
H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces---Haptic I/O.

INTRODUCTION
The field of human computer interaction has expanded its scope to material properties. For example, shape and volume [1], color of the 3D surface [2], optical properties [3], and stiffness [4] have been previously investigated. The principal goal of these investigations is to make physical properties of materials programmable and interactive. In this paper, we focus on density: one of the fundamental properties of the material. Density is a scientific concept defined as the mass of a substance per unit volume. Differences in density do not only mean differences in mass of atoms, but composite materials or hollow structures could have mixed densities. Based on the idea of mixed density, we propose a weight-changing method by using movable material such as liquid, powder, and granular materials. To maximize mass transfer for changing mixed density, we chose liquid metal as the material.

In order to specify any object we usually describe its color, size, and weight, for instance, in a product catalog or on an online store. We employ projection of color texture and volume-changing interface to augment the weight-changing device. The capability of changing weight, volume, and texture raises many research questions regarding how human perceive dynamically changing materials.

The weight-changing device can be used for haptic information representation, simulation, and motion control. In particular, density is a basic concept taught as part of regular science education. One of the possible uses of this device is to be used in basic science experiments or making exhibitions at science museum more interactive and playful.

We present the following contributions:

1) Propose a novel device with programmable mass and volume, 2) Demonstrate potential application of simulating objects with different weight/volume on the single device, 3) Motion control by using gravity force.

RELATED WORK

There are a few possible methods to provide weight-changing effect: 1) simulation of gravitational force, 2) weight perceptional illusion, and 3) mass transfer.

Gravity Grabber [5] is a wearable device that can produce false sensation by using deformation of the finger pads. The user experiences an augmented grip force, gravity force on a passive physical object. Traxion [6] is a tactile device that can produce illusory forces in a particular direction when users hold the device between the fingers. Other possible methods to exert virtual force to simulate gravity are using devices such as a robot arm or a wire driven system. For an untethered mechanism, using magnetic force, airflow, and rotorcraft would be the solutions.

There have been several works utilizing moving mass in user interfaces. Fillable [7] is a tangible controller using every day vessels (e.g. paper cups) with adjustable haptic by filling. They implemented two applications: drawing and video navigation. Weight-shifting mobile [8] is the mobile device that has actuated center of mass by shifting an internal weight. They proposed some applications, for example, augmentation of graphical contents, and haptic compass to navigate. Invisible [9] is a game system using vacuum-like interface with help of shadows, sounds, and weights. They used a water tank in a backpack to represent the weight of the virtual characters the player caught.

In several examples, the weight or balancing between masses is used as the metaphor to represent the importance or 'density' of digital information being represented [10].

WEIGHT-CHANGING DEVICE

System Overview

The weight-changing system is based on mass transfer using liquid metal (Figure 2). The system consists of two main components: a weight-changing object and a mass supply. The weight-changing object consists of a bladder and a shell that supports the bladder. The mass supply consists of a bi-directional pump, a liquid metal tank, and control circuits. The weight-changing object and the mass supply are connected with flexible tubing so that the user cannot recognize the mass transfer.

Theoretically, the range of controllable density is from near zero to the density of movable material. Therefore, to maximize the range, it's better to use heavy material for mass transfer. We chose Gallium-Indium-Tin eutectic (also known as Galinstan) with density of 6.44g/cm^3 in the system. The Ga-In-Tin eutectic is slightly heavier than eGaIn (Ga-In eutectic) with density of 6.25g/cm^3.
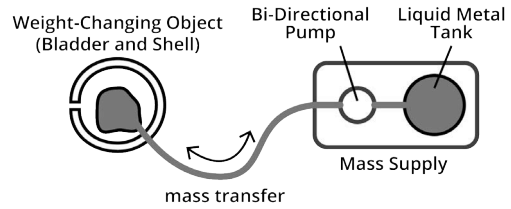

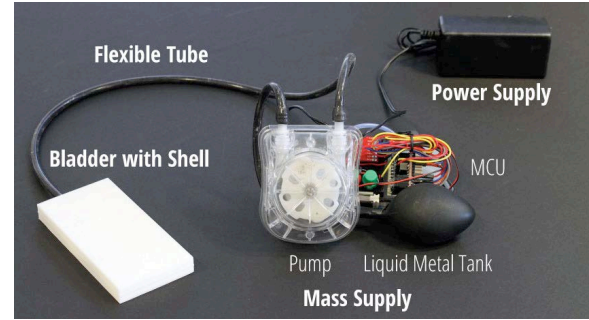Figure 2. Weight-changing mechanism with mass transfer

Figure 3. Implementation of the weight-changing system

Weight-Changing + Volume-Changing

We integrated a weight-changing device with a volume-changing function (Figure 4). The weight-changing device is embedded in a volume-changing interface. A pneumatically driven volume-changing mechanism is used in the system. For the volume-changing part, a tube for controlling air, and pneumatic control valves are added to the original system.
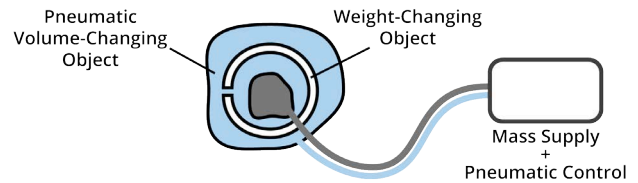

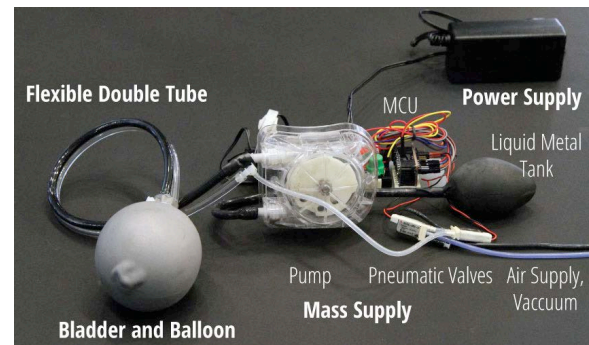Figure 4. Combination of weight-changing mechanism with pneumatic volume-changing

Figure 5. Implementation of the weight/volume-changing system

APPLICATIONS

Material Simulation

First application is a system for simulating density of materials (Figure 6) by weight changing. We chose a rectangular flat block with a fixed volume of 90cm^3

(H12.5×W120×D60mm) as the shape of the device to represent bulk raw material. We avoid using thick blocks because we found that users tend to recognize cubes or cylinders as hollow containers rather than solid materials.

The mass supply provides the flow of liquid metal between a liquid metal tank and a bladder in a rectangular flat shell. The liquid metal tank and the bladder are made of latex rubber and PVC film, correspondingly. The bladder has compartments to prevent imbalance and swinging motion of the liquid metal (Figure 6). The mass supply and the bladder are connected with flexible opaque silicone tubing with a diameter of 6.35mm so that the user can hold the device and test the weight naturally.

We pick a variety of materials for the demonstration of the simulator: pine wood ($0.50 g/cm^3$), water ($1.00 g/cm^3$), acrylic ($1.20 g/cm^3$), and aluminum alloy ($2.72 g/cm^3$). The color textures of the materials are shown in Figure 6.

a) Pine Wood ($0.50 g/cm^3$)   b) Water ($1.00 g/cm^3$)

c) Acrylic ($1.20 g/cm^3$)   d) Aluminum Alloy ($2.72 g/cm^3$)
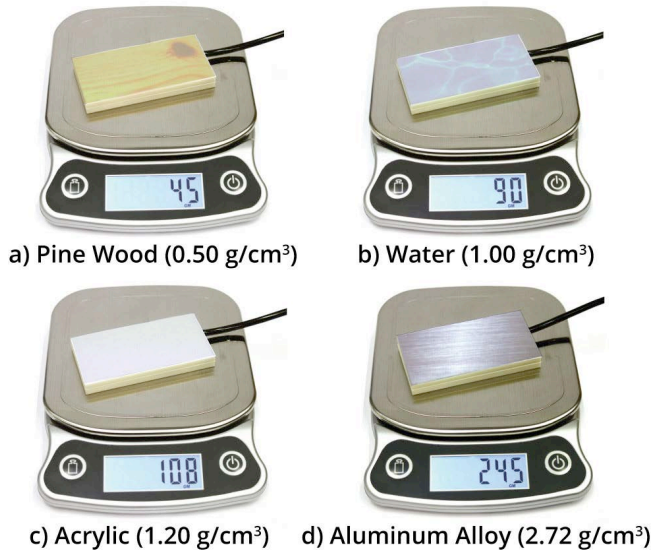
Figure 6. Material simulation using a weight-changing block with volume of 90cm³. The weight of the portable block is dynamically controlled corresponding to the density of target materials. Texture projection provides visual properties.

**Figure 7. Four textures used for the projection on the device.**

We demonstrate that the system can simulate density of four materials including natural material and liquid with projected textures (Figure 5). The advantage of the device is that it can provide hands-free, realistic weight feedback to the user. Moreover, unlike passive real samples of materials, it's easy to link with a computer network so that users can retrieve rich information about the background of the target material.

Miniature Solar System

The planets in the solar system are intangible because of their scale. Mass of the planet is determined based on the geological research. Here, we create a tool to compare the mass and size of the planets by using the mass/volume-changing device we proposed.

	Venus	Earth	Mars
Mass (10^{24} kg)	4.87	5.97	0.64
Comparative Mass	0.82	1.00	0.11
Diameter (km)	12104	12756	6787
Comparative Size	0.95	1.00	0.53

Table 1. Basic properties of the Earth and planetary neighbors, Venus and Mars.
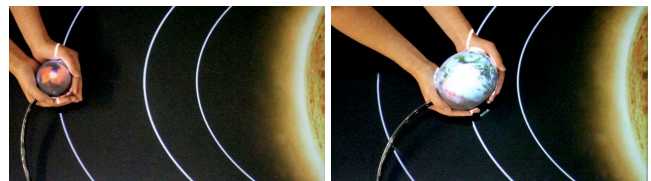
Figure 8. User can hold and move the device on the table with texture projection. The device changes the volume, weight, and texture corresponding to the target planet, for example from Mars (left) to Earth (right).

The user can hold the device to test the initial weight/size with texture projection. By choosing the orbit, the device can dynamically change its weight, size, and texture. In the implementation, we pick the Earth and its planetary neighbors, Venus and Mars.

Motion Control
Through the weight changing function, we can control the magnitude of the gravitational force to move physical objects. We demonstrate balancing control of lever and floating control underwater by using a weight-changing ball. The ball has a diameter 48mm, range of weight from 28g to 190g (density from $0.48 g/cm^3$ to $3.28 g/cm^3$).

Balance
A calibration weight (0.2kg) and the weight-changing ball are put on the each end of a lever made from square wood dowel. There are no moving parts and no actuators on the fulcrum. By controlling the weight of the ball, it can move the lever up and down.
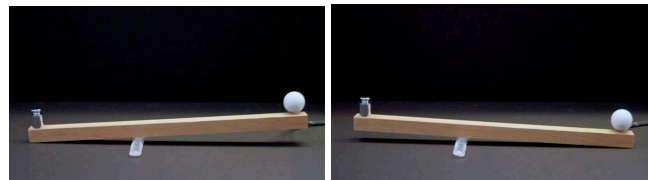
Figure 9. Balance control of a lever.

One of the possible applications of this quiet actuation is an ambient user interface with physical motion.

Float

Weight-changing device is capable of buoyant control underwater. Objects float or sink depending on their density. Through our methods, we can achieve neutral buoyancy, thereby holding the position of a ball underwater as well as move a ball upwards or downwards based on programming its density properties.
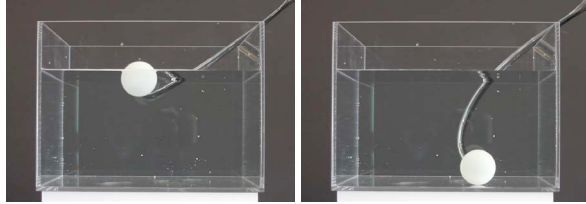

Figure 10. Floating control in a water tank.

DISCUSSION

One of the limitations of the proposed system is a limited controllable density range based on the density of liquid metal. In terms of density, mercury is heavier than Ga-In liquid metal. However, it's difficult to use mercury in user interfaces due to its potential chemical toxicity. The cost of liquid metal is another issue. For example, commercialized Ga-In eutectic costs $9.2/g (25g bottle, Sigma-Aldrich). We produce Ga-In-Tin eutectic on our own and it costs only $0.6/g.

We only used rectangular flat blocks and sphere shapes in our current implementation. The mechanism applicable for not only primitive shapes is pointing towards interesting approaches to future work. We can also further explore the design with multiple bladders for changing weight distributions in the same object. In the application scenario, material selection and object selection are used for switching density. We can also use physical concepts of adjusting temperature or pressure that can lead to changes in density. We will look into real world applications such as educational tools, entertaining games in science museum, and realistic mock-up models of product prototype.

New types of human behaviors and perceptual illusions are expected due to active weight changing. In order to explore this further, physio-psychological experiments are required, to probe, for example, dynamic versions of size-weight illusions.

CONCLUSION

We have presented a weight-changing device enabled by mass transfer. Liquid metal (Ga-In-Tin eutectic) is used as the working fluid for the system. The density of the device can be dynamically controllable from about 0.5g/cm^3 to 3.2g/cm^3. We show that the device can simulate a variety of materials from wood to light metal with projected color textures. We also integrate the device with a volume-changing function and create miniature planets with scaled size and weight. Programmable gravity force through the mass transfer can also be used for actuation, for example, balance control, and buoyancy control underwater. We envision a potential for programming additional material properties towards our vision of Radical Atoms [11].

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